Chapter 2
General Design Considerations

2-1. General

This chapter presents structural design considerations for outlet works structures used with embankment dams, or concrete dams with outlet works detached from the dam. A detached outlet works may be the most economical for a concrete dam when the dam is located in a narrow canyon with restricted space for the outlet features. The hydraulic design of outlet works is covered in EM 1110-2-1602. Intakes through concrete dams, normally called sluices, are covered in EM 1110-2-2200 and EM 1110-2-1602.

a. Outlet works. Outlet works consist of a combination of structures designed to control the release of water from the reservoir as required for project purposes or operation. The components of outlet works, starting from the upstream end, typically consist of an approach channel, an intake structure, a conduit or a tunnel, a control gate chamber (located in the intake structure, within the conduit, or at the downstream end of the conduit), an exit chute, an energy dissipater, and a discharge channel. Outlet works are frequently used to pass diversion flows during construction, regulate flood flows, aid in emptying the reservoir in an emergency condition, and permit reservoir lowering for inspections and special repairs. Typical arrangements of outlet works are shown in Figures 2-1, 2-2, and 2-3. The sizing of the outlet works should take into account the possibility of using it to reduce the size or frequency of spillway discharges. The necessity of emergency drawdown capability and low flow discharge capability should be considered during the outlet works planning phase. The selection of type and arrangement of outlet works structures should be based upon consideration of the costs of operation and maintenance likely to be incurred during the project life. Reliability under emergency flood conditions is a fundamental operational requirement of outlet works facilities.

b. Intake structures. The intake structure may serve several different functions in the outlet works system. Besides forming the entrance, it may include (1) a trashrack to block debris, (2) fish entrances, (3) multilevel ports or weirs for water temperature control, (4) temporary diversion openings, (5) water supply and irrigation intakes, (6) bulkhead or stoplogs for closure, and (7) control gates and devices.

c. Outlet tunnels or conduits. Water passage through or around the dam is provided through tunnels in rock abutments or through cut-and-cover conduits through the base of an embankment type dam.

(1) A tunnel in a rock abutment is preferred when it is more economical than other means and when topographic conditions permit its use. Narrow rock abutments, permitting a relatively short tunnel, are conditions preferable for tunnels. The selection of the number and size of tunnels depends on hydraulic requirements, the maximum size of tunnel for the rock conditions encountered, and overall economics. When a tunnel is used also for diversion, its sizing is often controlled by the diversion releases required during construction. Figure 2-1 shows a tunnel outlet works.

(2) Cut-and-cover conduits are economical for low- or moderate-head embankment dams because of lower construction costs and a shorter alignment. A typical cut-and-cover conduit is placed near streambed elevation, preferably outside the normal river channel to facilitate construction. It should be placed within the most competent portion of the foundation and, when practicable, on suitable rock to keep potential settlement to a minimum. High-head dams will require a thick concrete section to resist high embankment loads. Figure 2-2 shows a cut-and-cover outlet works.

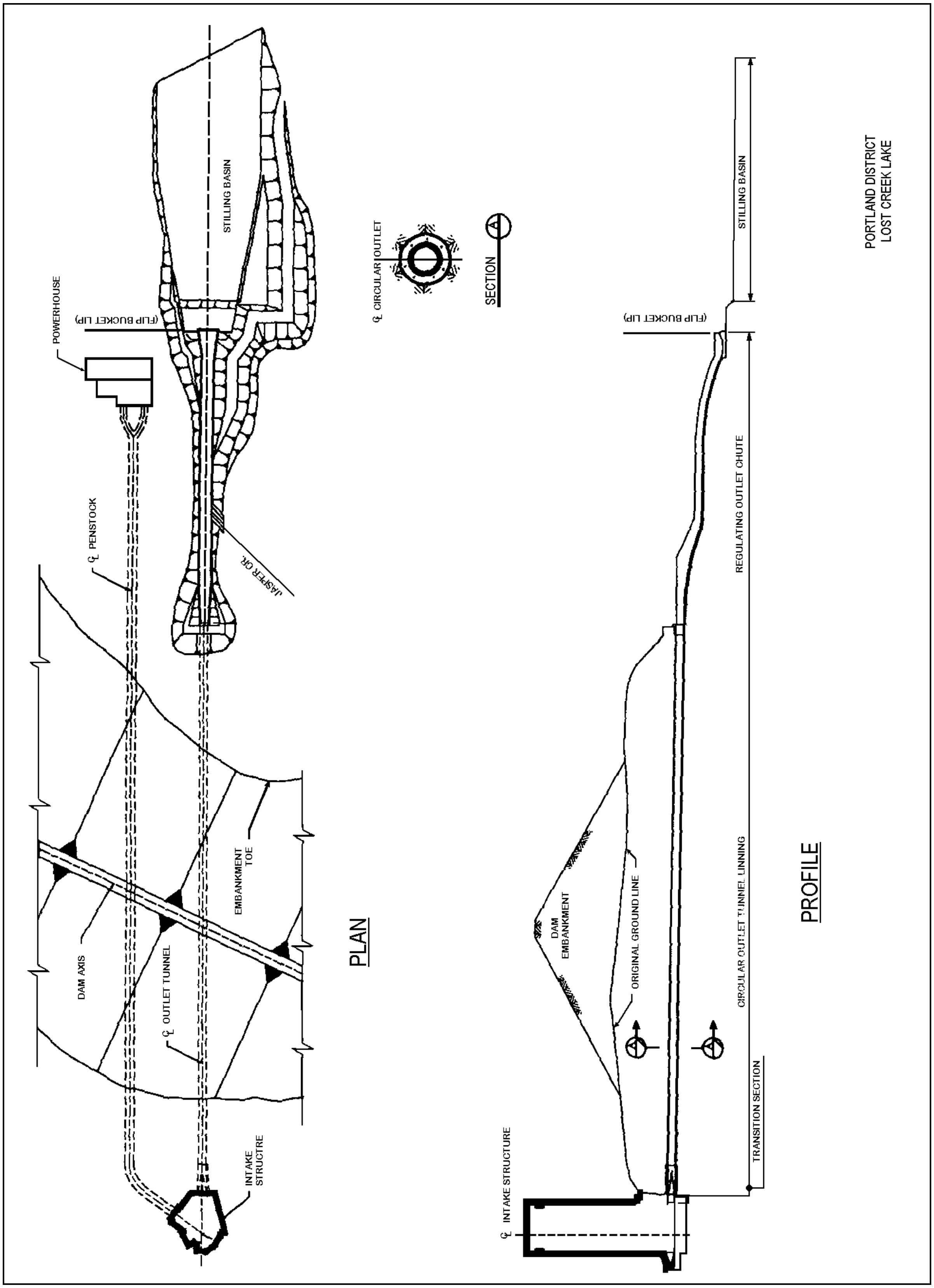

Figure 2-1. Outlet works through abutment, Lost Creek Lake, Oregon

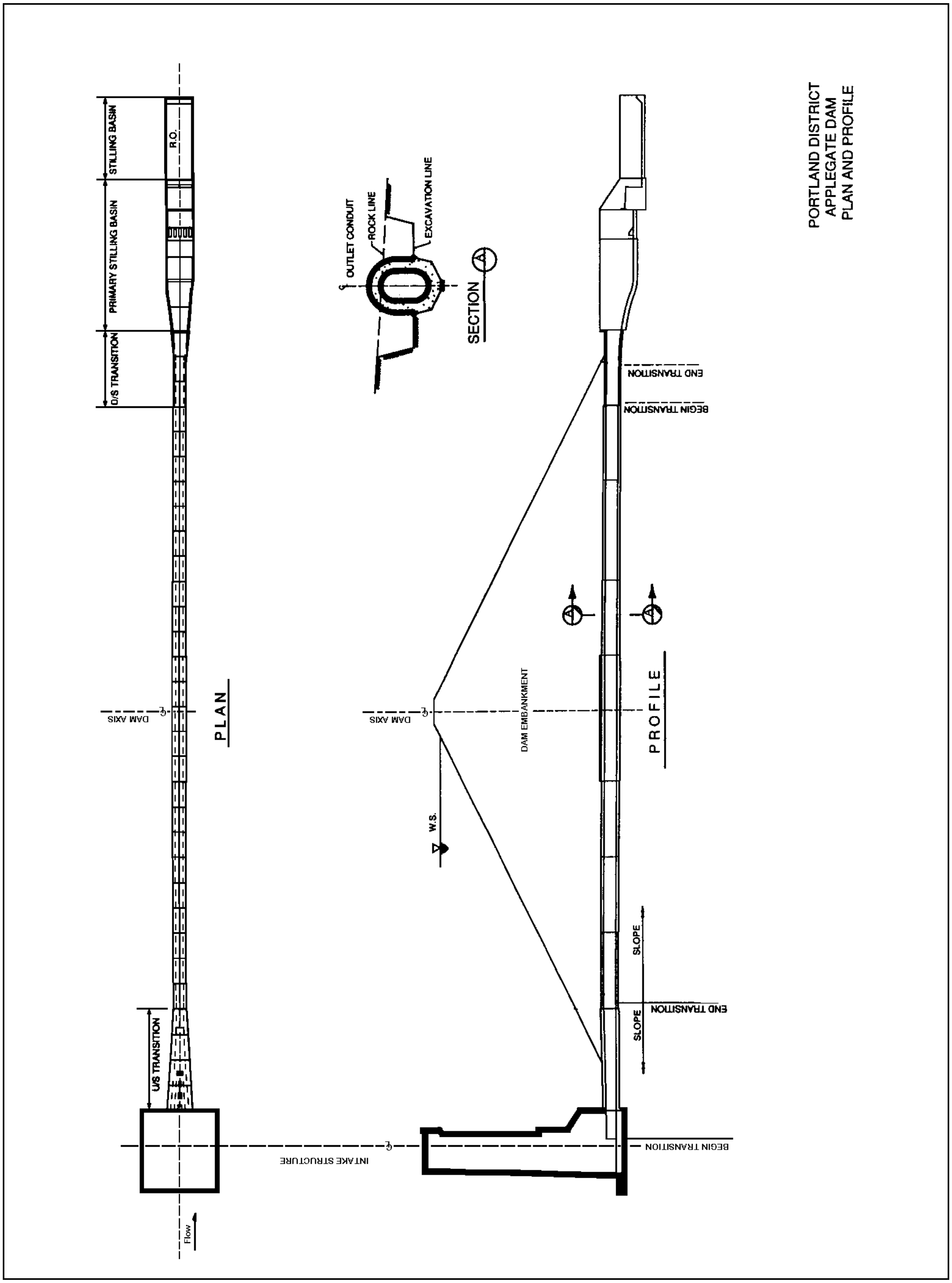

Figure 2-2. Outlet works under embankment dam, Applegate Lake, Oregon

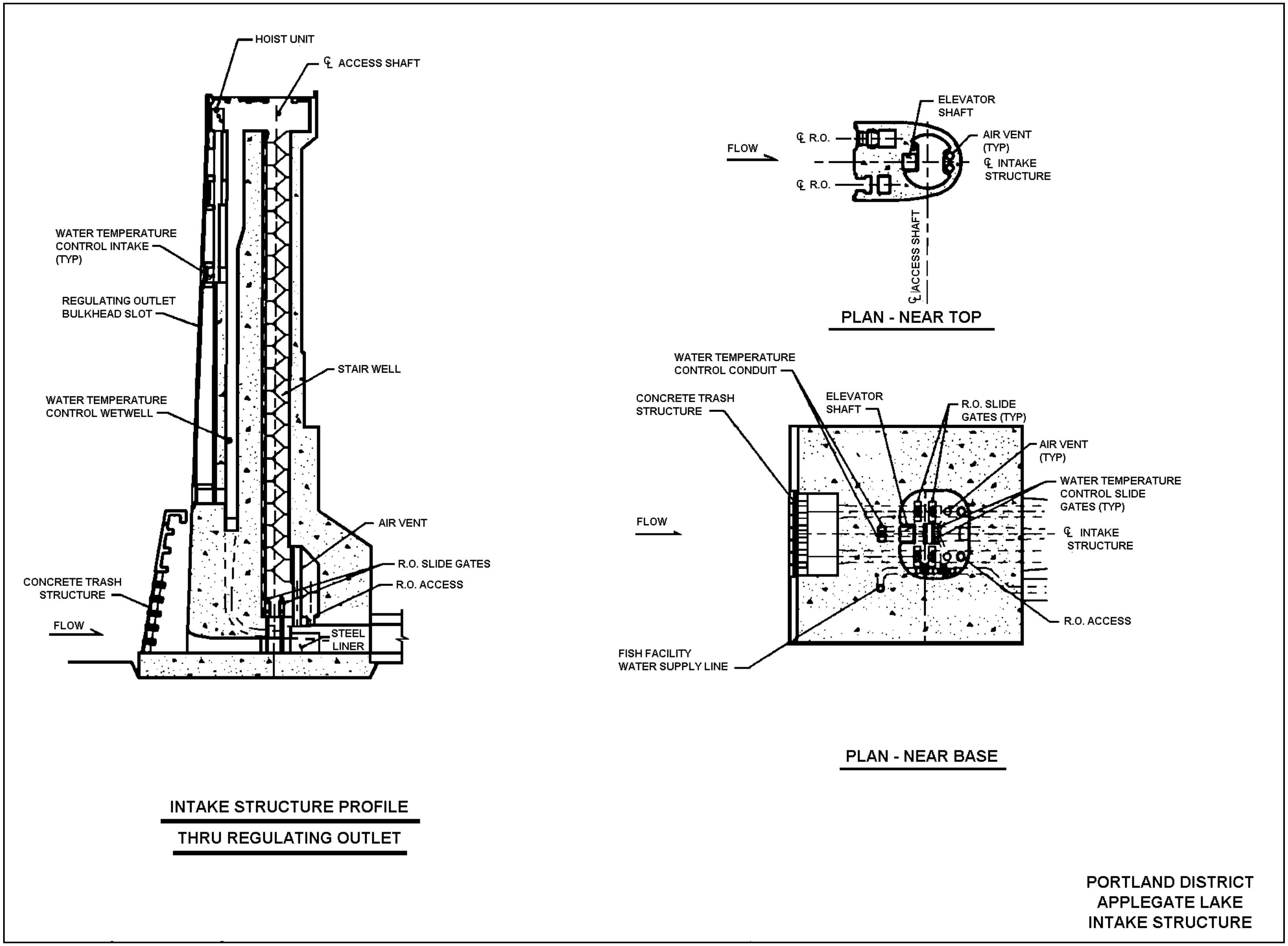

Figure 2-3. Vertical intake structure, Applegate Lake, Oregon

d. Control gating. Reservoir outlet works may be gated or ungated, depending on the project functions. Gated outlet works are needed for multiple-purpose reservoirs that provide storage for conservation, power, irrigation, etc. Gated outlet works are used also for single-purpose flood-control projects in which positive control of discharge regulation is required. Ungated outlets are adapted to some flood-control reservoirs, particularly small ones, where predetermined discharges (varying with the head) will meet the flood-control requirements. In general, the size of gates and conduits should be based upon diversion, evacuation, and operational requirements. A careful study and analysis should be made of the downstream channel capacity. The outlet works capacity should be adequate to discharge downstream channel capacity flows when the reservoir level is at the bottom of the flood-control pool. Consideration should be given to the time required to empty the reservoir for projects requiring emergency drawdown capability. The effect of rapid drawdown on materials at the reservoir margin must be considered. For gated structures, the number and size of gates should be such that one inoperative gate must not seriously jeopardize the flood-control function of the project. The use of two-gate passages is preferred for economy unless studies indicate the operating characteristics would be materially improved by the use of three-gate passages, or unless a wider structure is required for stability or structural reasons. The size of the gates should be based on an individual study for each project evaluating both the release capacity and downstream damage. The height of gates should generally be the same as the diameter of the tunnel or conduit in order to simplify the transition between the gated intake and the downstream tunnel or conduit. It is unlikely that large service gates will be able to regulate small flows with sufficient accuracy. This means, where low flow discharges are required, either a small gate within the service gate or a separate gate for small flows will be required. Usually, a separate gated system for low flow water and water supply regulation is the most reliable. In general, for medium height dams (heads between 80 and 120 ft) the most economical type of gate structure is one located at the upstream end of the outlet works consisting of a wet-well type structure with two gate passages, each passageway regulated by a hydraulically operated caterpillar or wheeled service gate with a single transferrable emergency gate operated by a traveling hoist located in the superstructure at the top of the intake tower. For high-head projects (heads over 120 ft) and for low-head projects (heads less than 80 ft), the most economical type of gate structure will often be different from that used for medium height dams. In any case, alternative studies will be required to verify that the type of outlet works structure selected is the most economical.

e. Exit chute and energy dissipater. Water flowing from the outlet works to the downstream river channel will be at high velocity. Energy-dissipating structures are commonly required to reduce flow velocities to levels that will not cause scouring, which can undermine tailrace structures and damage the downstream channel and riverbed. Energy-dissipating structures for outlet works may be similar to those found on spillways, such as hydraulic jump stilling basins or flip bucket plunge pools. Where releases are small, baffle block structures, riprap scour protection, or cut-off wall scour protection may be all that is required.

f. Approach and discharge channels. The purpose of the approach channel is to convey water into the intake structure. The discharge channel is designed to direct flows back to the river channel. The dimensions and alignment are determined by the hydraulic requirements and the stability of the excavated slopes.

2-2. Intake Structure Types

There are no standard designs for intake structures. Each design is unique and may take on many forms and variations. The intake structures discussed in this manual can be separated into two broad categories: free-standing and inclined. Selection of the appropriate type depends on a number of considerations including site conditions, economics, and effectiveness in meeting project requirements. Project requirements can include reservoir operating range, drawdown frequency, discharge range, trash conditions and required frequency of intake cleaning, reservoir ice conditions, water quality and temperature operating requirements, and environmental requirements such as fish passage. An intake structure may be submerged or may extend above the maximum reservoir water surface, depending on its function. Above-reservoir intake structures are necessary when gate controls are located on top of the structure, access to an internal gate control room is through the top of the structure, or when operations such as trash raking, stoplog or bulkhead installation, and fish screen cleaning are required from the structure deck. The submerged intake structure is primarily found at low-head, flood-control projects where submergence occurs only during flood periods or at projects where trash cleaning is not required. Submerged intake structures may also consist of simple submerged shafts and horizontal intakes equipped with a trash structure and bulkhead slots.

a. Free-standing structure. The most common type of intake structure is the vertical structure, generally referred to as a free-standing intake tower. It allows increased flexibility when locating the outlet works at the site. The vertical tower is usually more economical and easier to lay out than the inclined intake structure. Conduits and openings, operating equipment, and access features lend themselves more readily to arrangement in the vertical structure. A service bridge provides access to the top of the structure. Figure 2-3 shows a typical free-standing intake tower.

b. Inclined structure. For higher embankment dams in high seismic risk areas where a vertical structure may not be feasible, an inclined intake structure supported against the abutment is an alternative for consideration. An inclined structure has the advantage of increased stability over a vertical structure. In high-risk seismic locations and on steep abutment slopes, anchoring of the structure to the abutment to maintain stability and prevent liftoff should be investigated. Figure 2-4 depicts an inclined intake structure.

2-3. Functional Considerations for Outlet Works Facilities

The type and design of the outlet works facility will be greatly influenced by the project, its purposes, and structure-specific functions. An evaluation of each function is absolutely necessary in any design of the structure selected.

a. Flood control. Outlet works for flood-control projects generally require designs having large flow capacities and less regulation capabilities. Typically, the outlets are gated for flow regulation. However, the conduits may be uncontrolled (no gates) for reservoirs that are low or empty during non-flood periods.

b. Navigation. Projects releasing flows for downstream navigation usually involve lower discharge capacities than flood-control works. Requirements for close regulation of the flow and continuous releases are characteristic with outlets designed for navigation.

c. Irrigation. Gates and valves for irrigation require close regulation and lower discharge ranges than flood-control outlet controls. Releases may be discharged into a channel or conduit rather than into the original riverbed.

d. Water supply. Municipal water supply intakes are generally a secondary project function. Reliability and water quality are of prime importance in the design. Water intakes are located and controlled to ensure that the water is free of silt and algae, to obtain desired temperatures, and to allow intake cleaning.

e. Power. Power penstocks within intake structures should be located so as not to cause any undesirable entrance flow conditions such as eddies that might jeopardize turbine operation. Power intakes may require smaller trashrack openings to limit the size of debris that enters the penstock. Requirements for power intakes are covered in EM 1110-2-3001.

f. Low-flow requirements. Low-flow releases are required at some projects to meet environmental objectives, downstream water rights, water supply, etc. Smaller conduits and pipes separate from the main outlet conduits may be required to maintain minimum releases. Intake trashracks should be sized to prevent plugging of the smaller lines.

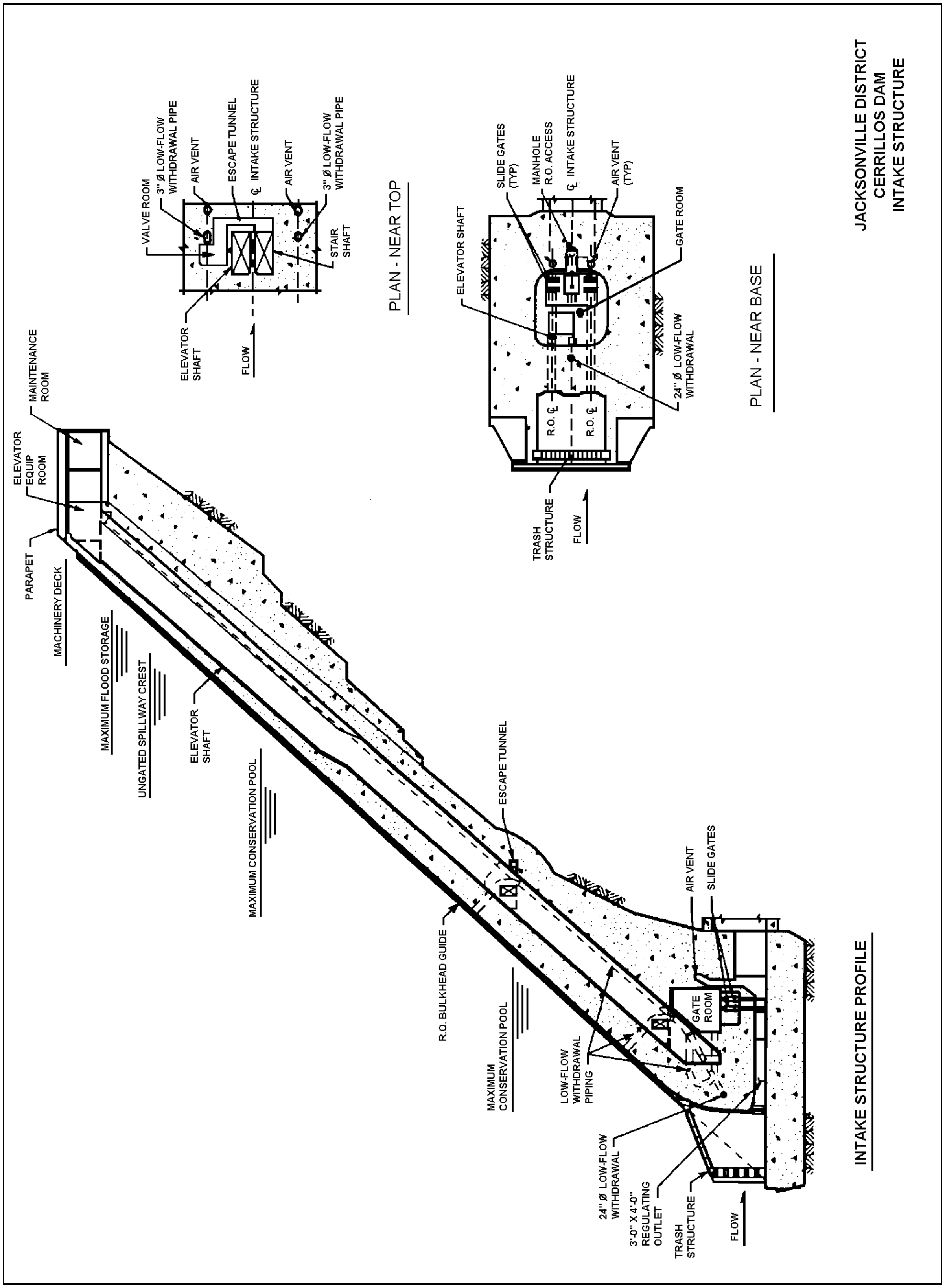

Figure 2-4. Inclined intake structure, Cerrillos Dam

g. Water temperature. Project requirements for fish and wildlife may involve intake features that control water temperature downstream of the reservoir. Multilevel ports and skimmer weirs in conjunction with a mixing wet well may be used to achieve this function. These features are incorporated separately or in combination with the other functions of the intake outlet works.

h. Sediment. Projects designed for sediment retention should be designed to pass flows as the sediment level rises in the reservoir and to prevent sediment from passing through and damaging or blocking both the entrance and the outlet works itself. Smaller releases are controlled by multilevel intakes that are closed by gating or stoplogs as the sediment level rises in the reservoir. For projects with flood flows that are released through the outlet works, a high-level intake that provides protection against large sediment buildup may be necessary.

i. Drawdown. ER 1110-2-50 requires that all new projects have low-level discharge facilities for drawdown of impoundments. Chapter 5 provides further discussion of this requirement.

j. Diversion. Outlet works may be used for total or partial diversion of the river during construction of the dam. The outlet works must be sized for both diversion and final project releases. A cut-and-cover outlet conduit that is used for diversion is typically located outside the normal river channel to facilitate ease of construction. Except for some high-head dams, it usually is economical to place an outlet tunnel near the river channel elevation, allowing its use for diversion. The scheduling and staging of the outlet works in conjunction with the dam construction require careful evaluation. This is particularly important when second-stage outlet works construction needs to be coordinated with dam closure and the ongoing diversion.

k. Outlet diversion with a high-level intake. An alternate plan used for some deep reservoirs includes a high-level intake structure at the head of an inclined tunnel connecting with a tunnel through the abutment near river level. After the river-level tunnel is used for diversion and construction is completed, the low-level tunnel is plugged at the upstream side of its intersection with the inclined tunnel and downstream portion of the low-level tunnel with a connecting curved transition forming the permanent outlet. Figure 2-5 shows an example of this plan. This plan may be economical and satisfactory under special conditions in which the reservoir is very deep and the site provides sound rock for supporting the intake structure and the complex tunnel construction. However, foundation investigations and comparative studies should be performed. The design will require low-level drawdown facilities as outlined in ER 1110-2-50. This plan should not be selected without full analysis of its practicability and economy.

2-4. Intake Tower Design Considerations

a. General. The outlet works is an integral part of a project that includes a dam and spillway. Its layout and configuration therefore should be associated with the planning and development of the complete project. In all cases, selection of the best overall plan for the outlet works should be made after careful comparative studies of alternative plans and consideration of the site conditions. Functional and service requirements, component interrelationships and compatibility, economy, safety, reliability, and repair and maintenance requirements should all be considered in the studies. Site conditions include topography, climate, foundation, geology, and seismicity. Hydrology and minimum flow requirements are important for determining the range of design releases for the outlet and diversion conditions. All operation and maintenance requirements must be identified in order that a safe, reliable, and economical outlet works will be designed. After all the purposes of the project are established and the functions and criteria for the outlet works have been clearly defined, the geometry and layout of the intake tower can proceed. Multiple alternatives should be developed and evaluated to determine the optimum plan.

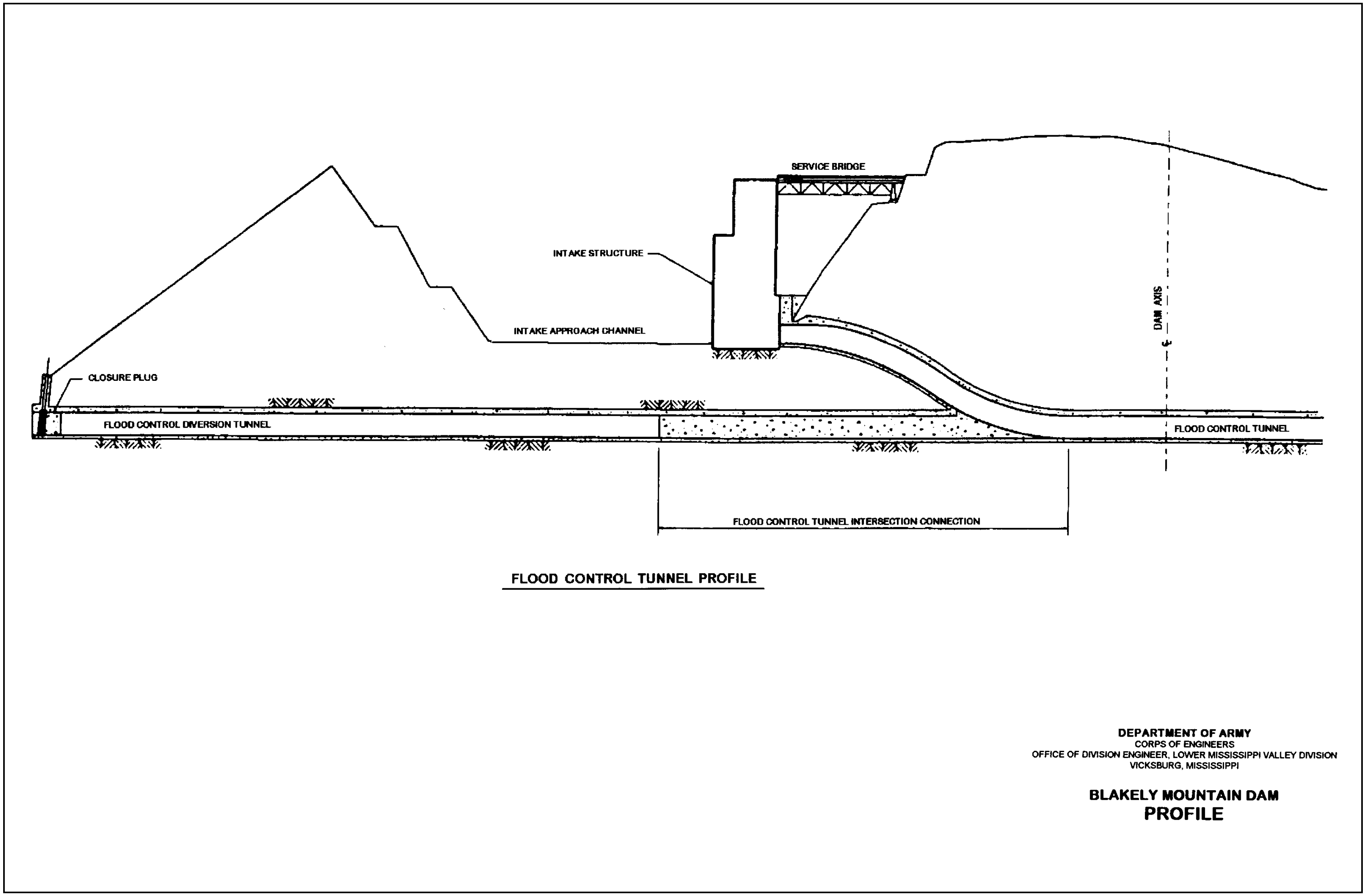

Figure 2-5. High-level intake, low-level diversion tunnel, Blakely Mountain Dam

b. Design considerations and criteria. The intake structure size and configuration are based on the inlets and collection wells size, control gate passages, inlet hydraulic configuration, exit passages, structural element size, and the space and clearance requirements for the mechanical and electrical equipment. The intake structure may take on numerous shapes and forms for each potential alternative. The final configuration will take the effort of a fully coordinated team of structural, mechanical, electrical, material, cost, and geotechnical engineers; a geologist; and hydrological and hydraulic engineers to ensure that all engineering and geological considerations are properly integrated into the overall design. When water quality is a consideration, reservoir hydrodynamics and environmental studies are important in the design process. Mathematical and/or physical hydraulic modeling may be required to support the hydraulic and environmental design.

c. Structural design considerations. After the design layout has been selected, the structural engineer should evaluate the structural integrity. One primary responsibility of the structural engineer is to ensure that the structural design meets the objective of carrying design loads from the top of the structure to the foundation. Wet wells with multilevel ports and weirs must be checked for structural stability, materials, sizing of members, connection details, reinforcement layout, and geometrical compatibility with adjacent features. The objectives of effective structural planning are to maintain symmetry, minimize torsional effects, provide direct vertical paths for lateral forces, and provide a proper foundation. A continuous load path or paths with adequate strength and stiffness that will transfer all forces from the point of application to the final point of resistance must be provided.

d. Siting. Selection of the location for an intake structure depends on multiple factors, including foundation approach conditions, alignment of conduit, and tunnel access. For an embankment dam, the structure is often located adjacent to a hillside into which the outlet works pass. For a cut-and-cover-conduit, the structure is generally located at the upstream toe of the embankment dam. The location and configuration of the structure will also depend on whether the structure will be vertical or inclined. For a vertical intake structure, the location will be determined largely by the design layout of the rest of the outlet works and the dam. However, adequate information about the foundation conditions should be obtained prior to the final site selection to ensure that the foundation will be suitable. For an inclined structure, the selection of the location of the base and the inclination angle are determined primarily by the ground profile and properties of the foundation materials present, e.g., depth of rock weathering, bearing strength, etc.

e. Water intakes. The water intakes are basically positioned with respect to the range of reservoir levels and to meet particular operating functions (project purposes). Low-level reservoir evacuation, sediment deposition levels, and minimum power generation are other criteria for consideration. Intake layout should consider the design of transitions, branches, heads, etc. A trash structure is required for most intakes to protect gates, valves, or turbines. The sizes of the trashrack openings are governed by the minimum waterways opening and the gate size. Further details on the trashracks and their design are provided in Chapter 5.

f. Locations of control gates. The control gates at U.S. Army Corps of Engineers projects are usually located in the intake structure, in a shaft or gate chamber near the extended axis of the dam, in the abutment under or within the dam section, or in one or both of the abutments. Under special conditions, the control gates may be located at the downstream end of a pressure tunnel. The principal advantages and disadvantages of alternative locations for the control gates are discussed in the following paragraphs. Control gates along the outlet and at the downstream end are discussed only briefly. The discussions are applicable to outlet works without diversion and to those with diversion.

(1) Control gates at upstream end. When the gates are placed at the upstream end of the outlet works, the emergency gates, bulkheads, service gates, and trash structures are all combined into a single structure. Closing of the gates allows for inspection and repair of the entire tunnel and for readily removing accumulated trash, sediment, or other deposits. A combined structure is particularly advantageous in cases in which

the permanent conservation or maximum power pool elevation is well above the river level. When other locations are selected for the gate structure, a separate structure for trash removal and bulkhead closures would generally be more expensive. With the control gates at the upstream end, the internal hydrostatic pressure in the tunnel is less than the weight of the overlying rock, earth, and water at all points along the conduit/tunnel profile. A disadvantage with upstream control gates is the cost of extending the structure above the pool and requiring an access bridge. The upstream gate location is preferred when the cost is nearly the same or even slightly higher than that for other gate locations. The upstream closure of the outlet conduits with the control gates provides additional dam safety. The types and limited sizes of gates or valves suitable for use under high heads sometimes require multiple gates in wide intake structures and long transitions between the gates and the outlet tunnel or conduit.

(2) Control gates near dam axis. Placing gates in a gate chamber or shaft in the abutments provides increased protection at high-seismicity sites. Disadvantages include the requirement of a separate bulkhead closure at the upstream end to provide the capability of dewatering the upstream portion of the tunnel for inspection, access for operation and maintenance, and designing for high earth loads where the gate is located in an embankment dam. Tunnels and conduits upstream of the gate chamber will need to be designed for full internal hydrostatic heads.

(3) Control gates at downstream end. Full internal hydrostatic pressure over the entire outlet tunnel requires a steel lining inside the concrete lining to prevent unsafe hydrocharging through cracks in the concrete liner of the surrounding rock near the downstream end. The length of the steel lining will depend on the geologic conditions and the depth of rock over the tunnel. This requirement generally makes this alternative less economical. The downstream location may be favorable in special conditions such as high-head projects and short outlet tunnels. As with the location along the dam axis, upstream bulkhead closure is required.

g. Intake structure shape. There are numerous geometric shapes and combinations that can be developed in the design of an intake structure. The elevational profile can be uniform or tapered, and the plan can be rectangular, circular, or irregular. The following paragraphs discuss three basic geometric shapes.

(1) Rectangular. Rectangular intake structures are more functional for low-head reservoirs that are designed for large discharges. A rectangular shape provides for more efficient layout of entrances and openings, gates and operating equipment, and other features. Rectangular intake structures are usually more easily constructable and site-adaptable. Figure 2-6 shows a rectangular intake structure.

(2) Circular. Circular intake structures are structurally more efficient, providing economic savings, particularly in high-head projects. Hydraulic and access requirements can readily be adapted to the circular shape. The lower section of the structure may be rectangular to provide for arrangement of the water intakes, trashracks, and bulkheads.

(3) Irregular. An irregular design may result in the development of very complex and unusual shapes. Structures with wet and dry wells, high-level intakes, multiple wet wells, fish entrances, and other special features result in numerous different and unusual configurations. Figure 2-7 shows an irregular intake structure.

h. Wet well. Wet wells of intake structures are used to withdraw water from different levels of the reservoir and for mixing to achieve specified controlled temperature releases. Wet wells are also used for multi-port sediment retention where ports are closed with stoplogs as the sediment level rises in the reservoir. Wet wells can be sized as a single unit or several wells.

i. Dry wells. Dry wells, also referred to as access shafts, provide access to the gate room when located near the base of the intake structure. Features commonly incorporated into a dry well are elevator, stairs, air

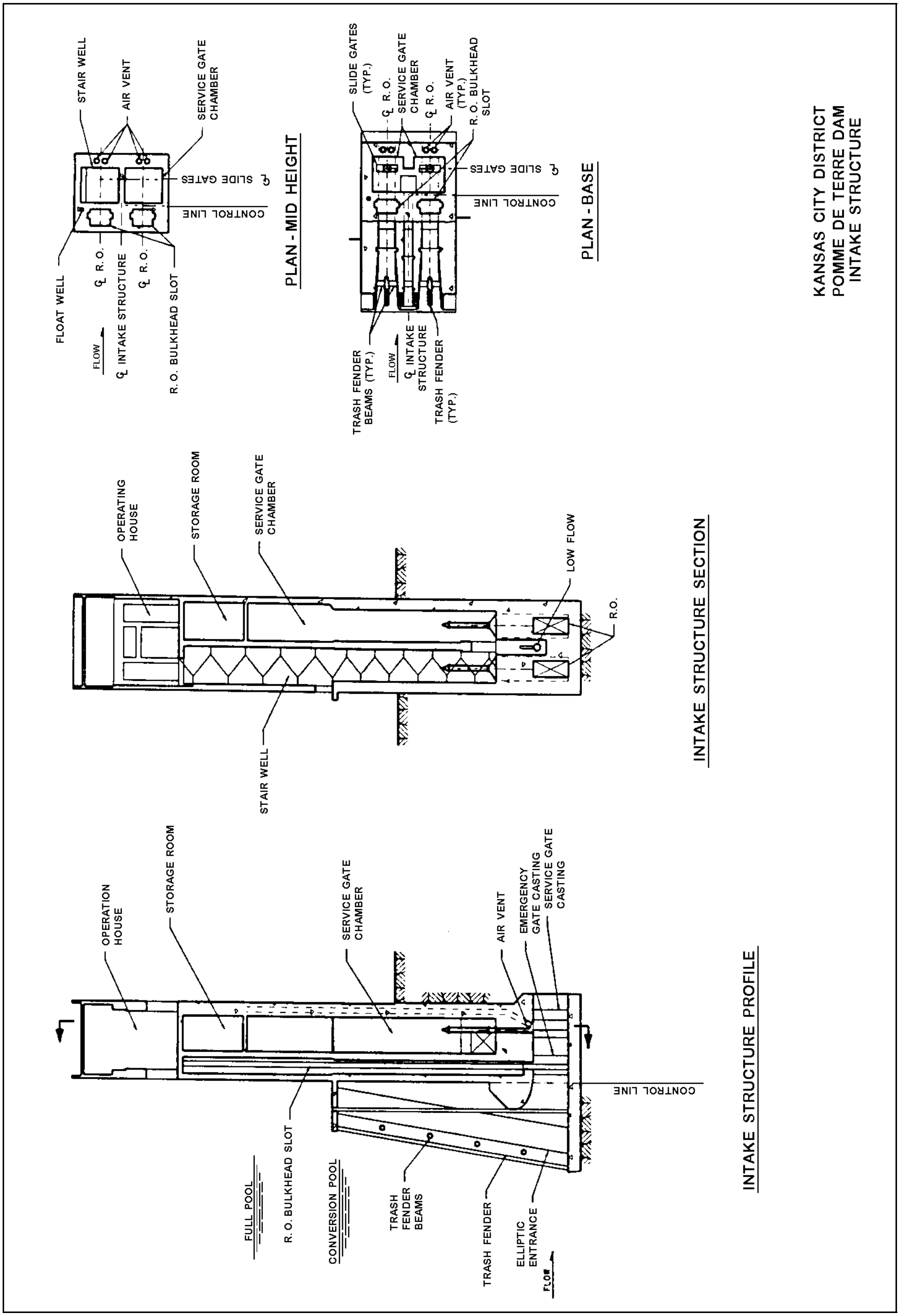

Figure 2-6. Rectangular intake structure, Pomme De Terre Dam

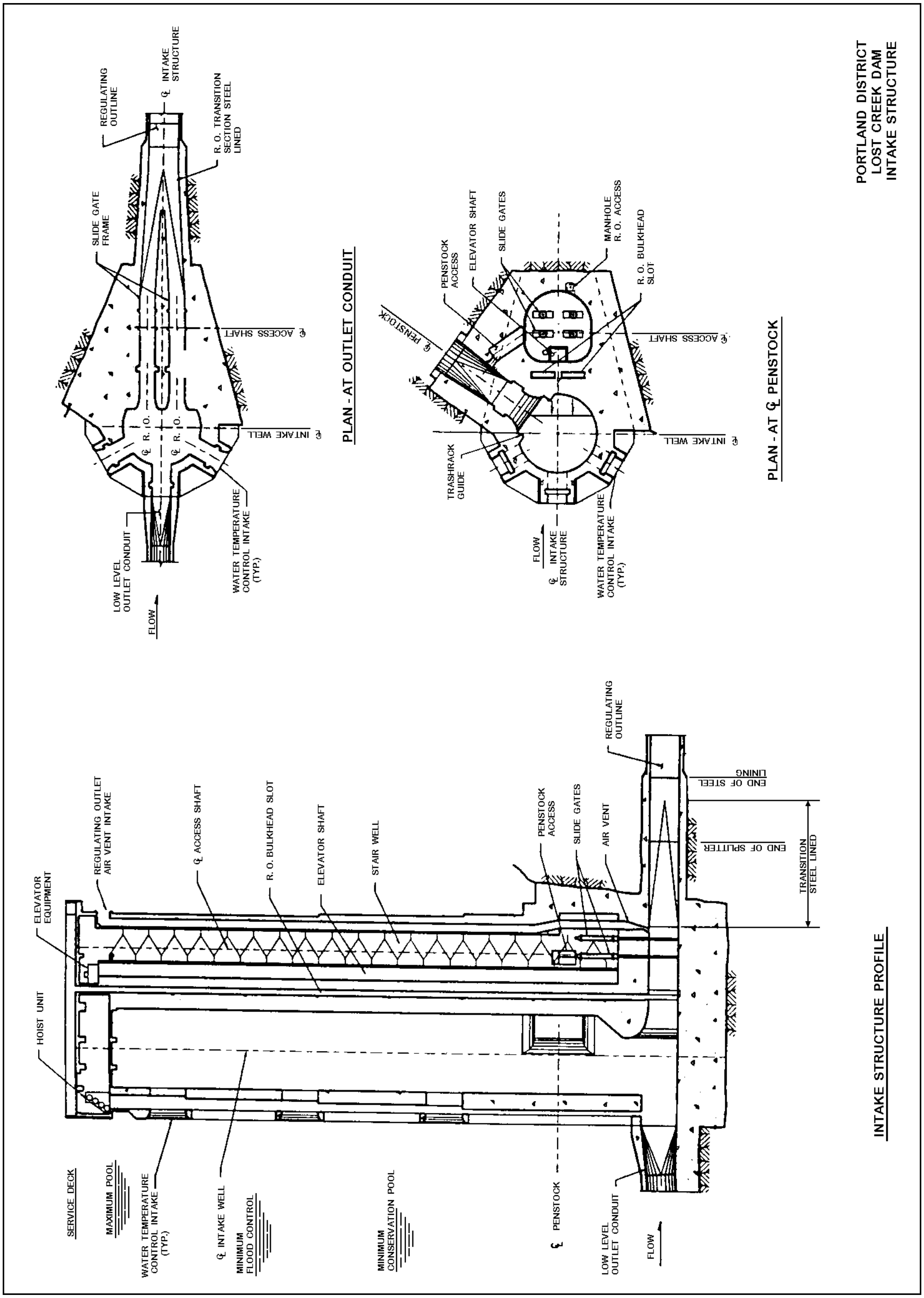

Figure 2-7. Irregular intake structure, Lost Creek Dam

vents, and an open shaft area for the removal and installation of equipment for repair and maintenance. These features should be arranged in the most efficient manner to minimize the dry well size. The open shaft area in the dry well should be sized to allow removal of gates and other gate room equipment.

j. Gate room. Gate room design with both service and emergency gates is outlined in this paragraph. When hydraulically operated slide gates are used, the service and/or emergency gates are usually located in a room in the base of the dry well. This arrangement is applicable to a single-conduit outlet works for a structure at the upstream end of the outlet works, a shaft near the dam axis, or a gate structure near the downstream end of the conduit. A circular-shaped gate room may be advantageous, especially for a high structure. When caterpillar or wheel service and emergency gates with downstream seals are used, the typical gate structure for a single-tunnel outlet works is of the wet well type (usually rectangular in horizontal section) with partition walls between the gate chambers dividing it into separate gate wells. The partition walls make possible the dewatering of any service gate by placing a single emergency gate in a guide upstream of the wall. This type of structure is used also for mechanically operated slide gates with gate stem extensions but is economical only for low-head structures. The water passages at the bottom of the structure are made with gradual transitions at the entrance and downstream from the gates. The intermediate and exterior walls of the passages are made the minimum thickness required to accommodate the gate frames and to withstand the hydraulic forces and structure loads. Minimum access provisions between the operating deck and base of the gate structure should consist of a ladder. In a dry-well structure, a stairway to the gate chamber is desirable. When the gate chamber is located more than 50 ft below the operating deck, an elevator of minimum size and capability is reasonable in addition to the stairway.

k. Basic architectural considerations.

(1) Functional design. Architectural design should focus on meeting operational, safety, and material requirements to include the following:

(a) Access/egress to/from the structure and movement within the facility shall comply with the latest edition of the NFPA 101, Life Safety Code. This includes design of such items as guardrails, walls, partitions, corridors, stairs, doors, etc. Ladders shall be designed in accordance with the requirements of EM 385-1-1, Appendix J. Compartmented storage or other specialized space features shall be incorporated in accordance with the latest edition of the International Code Counsel (ICC), International Building Code (IBC), and National Fire Protection Association (NFPA) requirements.

(b) System and materials should be selected based on durability, maintainability, economy, and aesthetics. Materials should conform to the Corps guide specification requirements and to nationally recognized industry standards. Selection should consider availability and future replacement to minimize first costs and costs associated with maintenance and repair. Exterior components should be selected and located where damage by vandals will be precluded.

(2) Aesthetic design. Locale must be considered in determining the exterior visual design of an intake tower. Geographical effects such as prevailing weather patterns should be considered in placement and protection of access points or other openings. The relationship of the tower to other existing or proposed structures should be considered and a compatible style or details developed. Remote sites with little opportunity for public access and limited visibility require less architectural treatment than sites where the tower can easily be viewed or visited by the public. When surface treatment of concrete is being considered, EM 1110-1-2009 should be followed.

2-5. Outlet Tunnels Design Considerations

a. General. The location of an outlet tunnel or tunnels is affected by topography, abutment foundation conditions, hydraulic requirements, and economy of construction. Except for some high-head dams, it usually is economical to place an outlet tunnel near stream elevation and use it for diversion during construction. A tunnel should be located far enough into the abutment to obtain adequate cover for the character of rock encountered, and the tunnel alignment must meet the hydraulic requirements. The most economical location to pass around or under the dam and meet the foregoing requirements should be selected. An alternate plan used for some deep reservoirs has a high-level intake at the head of an inclined tunnel connecting with a tunnel through the abutment near river level (see Figure 2-6). After serving its purpose of diversion during construction, the low-level tunnel is plugged at the upstream side of the intersection and the inclined tunnel and downstream portion of the low-level tunnel with a connecting curved transition from the permanent outlet (see Figure 2-5). This plan may be economical and satisfactory under special conditions where the reservoir is very deep, the minimum water surface is high, and rock foundation is adequate. Because of the difficult foundation and structural problems involved in this type of construction, thorough foundation investigations and comparative studies should be made and this plan should not be selected without full analysis of its practicability and economy. The advantage of the high-level intakes for a very deep reservoir is the lower intake structure and lower head on intake gates, resulting in a less expensive intake structure. Disadvantages of this type of outlet are: cost of the inclined tunnel, difficulty of obtaining an adequate foundation for the intake structure, and the difficulty of excavation for and the complexity of the transition structure at the junction of the inclined tunnel with the low-level tunnel. Particular care should be taken to obtain high quality concrete, smooth gradual curves, and good alignment at the junction. If the intake structure is located directly over the low-level tunnel, there should be an ample thickness of good, sound rock between the intake base and the tunnel to transmit the foundation loads to the main rock mass. Sometimes conditions may be favorable for locating the intake far enough to one side of the low-level tunnel to simplify the problem of supporting the intake structure. For some high dams, outlet works separate from diversion facilities and located much higher than the river channel may be suitable. In such cases, overall economy may result from use of separate high-level outlets and use of the downstream portion of the diversion tunnel as part of the spillway outlet.

b. Number and size of tunnels. The proper selection of number and size of outlet tunnels depends on hydraulic requirements, the maximum size of tunnel which it is practicable to drive in the rock encountered, operating flexibility, and economy of construction. In some instances it may be necessary to limit the size of tunnel in yielding rock to prevent excessive movement in the surrounding rock. Generally the larger the tunnel within practicable driving limits, the more economical it is per unit flow capacity. Also, the approach and discharge channels and the intake structure usually are more economical for fewer tunnels because the reduced width results in less channel excavation and a narrower intake structure. However, if it is necessary to use two parallel gates in each larger tunnel and only one in the smaller, the intake structure may not be reduced and economy may not be affected by use of larger tunnels. The most economical number of tunnels which will meet the other requirements should be used. A single tunnel is used when, as is frequently the case, the required diameter to handle the entire discharge is not over 20 ft to 25 ft. In order to provide reasonable operating flexibility, a total of not less than two service gates should be provided in the outlet works. In some cases, this requirement may influence the number of tunnels. Detailed design and construction procedures for tunnels are provided in EM 1110-2-2901, “Tunnels and Shafts in Rock.”

c. Approach and discharge tunnels. The dimensions and alignment of the excavated approach channel upstream from the river to the tunnel and of the discharge channel to convey the water back to the river downstream are determined by the hydraulic design requirements and the stable slopes for the material excavated.

2-6. Cut-and-Cover Conduit Design Considerations

a. General. A typical cut-and-cover conduit through an embankment dam is near stream bed level so that it will economically fulfill the hydraulic requirements for the outlet works and serve for diversion during construction. This conduit is placed on suitable rock whenever practicable, as good foundation is of paramount importance to keep settlement as small as possible. The most economical location which provides a good foundation is selected. When practicable the conduit is placed outside the normal river channel to facilitate construction. A location to one side of the river valley often provides the best foundation. Where the conduit sides are placed against rock, presplitting should be used to obtain close control of excavation. Water leaking from or onto the cut-and-cover conduit can lead to piping of embankment dam materials and jeopardize dam safety. Care must be taken when using cut-and-cover construction to assure that the conduit will remain watertight. The use of cut-and-cover construction where the conduit will be pressurized (gate structure near axis of dam or at downstream end) is unacceptable because leakage into the embankment under the higher internal water pressure would be dangerous should a rupture of the conduit occur.

b. Arrangement of multiple conduits. Multiple outlet conduits usually are placed close together so that the intake structure may be the minimum width that will satisfy the hydraulic and structural requirements. They should be planned to minimize cracking by keeping the conduit width to a minimum. This is accomplished by a single multiple-opening conduit structure with longitudinal contraction joints between conduits and generally not more than 50 ft apart. Detailed design and construction procedures for conduits are provided in EM 1110-2-2902, "Conduits, Culverts and Pipes."

c. Approach and discharge channels. The dimensions and alignment of the excavated approach channel upstream from the river to the tunnel and of the discharge channel to covey the water back to the river downstream are determined, in general, by the hydraulic requirements and the location of stable slopes for the material excavated. Concrete retaining walls are provided as needed just upstream from the intake and the trash rack to retain the upstream toe of the embankment on each side of the approach channel and similar retaining walls are provided at the downstream end of the outlet works, if required.

2-7. Energy-Dissipating Structures Design Considerations

Most often the type of energy-dissipating structure needed will be determined by hydraulic model studies. These studies should also be used to determine the loadings to be expected on the energy-dissipating structure during all flow conditions up to the Maximum Design Flood (MDF). Energy-dissipating structures may consist of (a) abrupt expansions in high pressure conduits, (b) hydraulic jump-type stilling basin structures, (c) flip bucket plunge pool structures, valves, and deflectors which spay jets into the air before entering a plunge pool structure, and (d) various baffle block energy-dissipating structures. The stability of the various energy-dissipating structures will be determined in accordance with EM 1110-2-2502. Information on spillway-type stilling basins can be found in EM 1110-2-2200. The structural design of energy-dissipating structures will be in accordance with the provisions of EM 1110-2-2104. The hydraulic design requirements of these structures can be found in EM 1110-2-1602.

2-8. Coordination Among Disciplines

The structural engineer should be involved in technical coordination of structural features during all project phases. Structural design activities should be coordinated with other functional elements of geotechnical, hydrology, hydraulic, mechanical, electrical, and architectural design, construction, operations, cost engineering, real estate, surveying, mapping, etc., to develop the design of the structural features. Technical coordination should be maintained with the technical staff of the local sponsor. Also, technical coordination with higher authority is encouraged to reach early agreement on unprecedented or complex problems.